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Evaluating the role of citizen science in biological investigations

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Abstract

Considering recent and predicted ecological changes (caused by global climate change), baseline monitoring of biological diversity becomes an extremely useful record to have. Citizen science provides a unique, low-cost, high output method of attaining large data sets which has already been implemented in several studies. They are used by major bodies such as the Natural History Museum, OPAL and the RSPB. Despite this concerns lie with the accuracy of the data – can volunteers really produce real data? In this study various aspects were investigated, firstly the current public opinion about citizen science, how we can train volunteers carrying out surveys, and the kinds of method suitable for biological monitoring by citizen scientists. This report finds a generally good level of public literacy in terms of the existence and the potential of, citizen science. Participant confidence significantly increases once a volunteer has carried out a survey – but this does not show any relationship with accuracy. It is concluded that estimation of abundance must be embedded with training and validation methods, and it is recommended further work is carried out into robust online training and validation.

Introduction

Climate change poses one of the most significant threats to global biodiversity and ecosystem functions (Omann, Stocker & Jäger, 2009). Monitoring changes to populations and ecosystems requires wide spread biological monitoring. Large data sets for monitoring on this scale are both logistically difficult, and costly to obtain. Therefore, biological records often lack "base-line" data. This information can be vital following changes to ecosystems such as oil spills, deforestation, and the effects of climate change. Furthermore, assessing human impacts can be hindered by a lack of prior information.

In an ecological context, citizen science is emerging as a significant provider of information, which continues to evolve in both its breath and the number of projects (Newman et al., 2011). Citizen science refers to the involvement of untrained, non-professionals in scientific research projects (Dickinson et al., 2012; Tulloch et al., 2013; Pocock et al., 2017). Usually this means volunteers who are members of the public taking part in either data collection or data processing (Silvertown, 2009; Welden, Wolsely & Ashmore, 2018), in either long term schemes or in shorter one-off projects (Dickinson et al., 2012).

Although having recently gained popularity, citizen science can be traced right back to the dawn of scientific discovery, for example Charles Darwin sailed upon the Beagle as an "unpaid companion" (Silvertown 2009); in this way he could be regarded as being a volunteer collecting scientific data (Silvertown 2009). Although it may be argued that at this time Darwin was in fact a scientist in training. At present, citizen science generally refers to the collaboration between the public and professional bodies on specific projects (Silvertown, 2009; Dickinson et al., 2012; Tulloch et al., 2013; Pocock et al., 2017; Welden, Wolseley & Ashmore, 2018).

Another early example of citizen science is the Christmas Bird Count, led by the National Audubon Society since 1900 (Dunn et al., 2005). During bird counts volunteers carry out a census of the local ornithology. Groups of volunteers cover a "count circle" with a diameter of 15 miles. A minimum of ten volunteers, break up into small parties and follow assigned routes within the circle. Whilst doing so they count every bird that they see (Dunn et al., 2005). This is geographically the most-wide spread ornithological survey covering a large proportion of north America and Canada. It is also the longest running survey of its kind in the Western Hemisphere (Dunn et al., 2005). Being one of the first projects of its kind, this highlighted many issues which needed addressing in such large-scale data collection. For example, the requirement for consistent training of volunteers, and the need for the data to be uniform, and reproducible. It was not initially ensured that participants only counted living birds, not those found dead at the side of the road (Garbarino & Mason, 2016). This is a simple problem to fix – however it relies upon dissemination of detailed protocols which are accessible and understandable to the volunteers. The Christmas Bird Count fills the expectation, historically, that citizen science is primarily associated with making skilled observations, for the most part this is true, but from the early 2000s citizen science was able to expand due to the prevalence of the internet (Garbarino & Mason, 2016).

The internet is advantageous as it allows citizen science projects to disseminate detailed protocols and new data collection methods to a large majority of the population, opening many new avenues for the scope of biological monitoring by citizen science (Garbarino and Mason, 2016). These are alternatives to traditional methods such as recording sightings, as now volunteers can carry out much more detailed surveys. This ability to transfer such information so easily, is met with more and more people seeking opportunities engage in nature. This has been boosted greatly with more publication of the health benefits of being outside (Pearson and Craig, 2014). As a result, citizen science has seen a vast rise in popularity in the last few decades (Kerr et al., 2007; Silvertown, 2009; Devictor, Whittaker and Beltrame, 2010; Roy et al., 2012). Furthermore, it has become a tool for greater public engagement in science (Silvertown, 2009; Dickinson et al., 2012; Pocock et al., 2017). A review by West and Pateman (2016) describes that one of the reasons for participation in citizen science is underpinned by the important role volunteering holds within society. Volunteering in the context of citizen science comes from a range of motivations which can vary according to demographic (West and Pateman, 2016).

The nature of citizen science lends itself greatly to biodiversity monitoring, and therefore many projects are wildlife-focused (Dickinson et al., 2010). Utilising the power of the public can have an advantage in overcoming the constraints of funding by allowing data collection from much broader geographic and temporal scales (Tulloch et al., 2013; Pocock et al., 2017; Welden, Wolseley and Ashmore, 2018). In ecology, citizen science is therefore a useful method of data collection which can be vital in gathering baseline data, monitoring populations, and reaching far more broad scales that other investigations, in order to produce large and readily available data sets (Dickinson et al., 2012; Tulloch et al., 2013; Welden, Wolseley and Ashmore, 2018).

The scope of citizen science is very wide. Citizen science involving large cohorts of volunteers allows us to overcome usual limitations such as lack of funding (Mackechnie et al., 2011), lack of public understanding (Jordan et al., 2011), and inadequate local involvement (Danielsen et al., 2009). Members of the public will fail to protect an environment they do not care about or have not experienced; however citizen science facilitates an increase in scientific literacy (Bonney et al., 2009) which may be able the change both attitudes and behaviour in relation to conservation (Toomey and Domroese, 2013), whilst also compiling large data sets and low costs, which are of huge ecological value (Dickinson and Bonney, 2012). Bonney et al. (2009) described that citizen science projects can be categorised into three categories, “contributory”, “collaborative” and “co-statistically similar to those of professional biologists, however there was more variation in the volunteer data. This meant that although the same means were attained, volunteer data showed a much greater range, which can raise questions about the accuracy of volunteers. Similarly, Moyer-Horner, Smith and Belt (2012) showed that sitting surveys carried out by volunteers could be used to reliably detect pika site occupancy, however some elements, such as accurate species identification or interpretation of behaviours, were better left to professionals.

Gardiner et al., (2014) investigated citizen science schemes in the UK and USA which monitored Lady Beetles. They showed that if researches had relied solely on the data collected by citizen scientists it would have significantly impacted on their interpretations of richness, species diversity and relative abundance. For example, misidentification of one species led to underreporting, whereas rare species were often overreported. However, evaluations from the Lakewatch citizen science project found that citizen scientists were just as accurate as biologists in gathering samples relating to water quality (Canfield et al., 2002). However, in this project the volunteer role was more focused on obtaining samples for analysis, rather than making their own biological observations. Therefore, due to the high variation in data collection methods, it is generally difficult to quantitatively evaluate the quality of data in citizen science projects (Aceves-Bueno et al., 2017). Individual projects often carry out their own assessments of accuracy and “screen” data to only use certain values, however overall comparisons of projects are limited, but should be done in order to facilitate future growth of citizen science.

To address this issue in this study four different citizen science methods were trialled using a survey group based at FSC Dale Fort in Pembrokeshire. Volunteers from the local area attended the group for either one or multiple survey days. There was no obligation to return for multiple surveys and participants consented to the use of their data in this study. Their data was used to assess the influence of different factors on the data collected by volunteers. Providing insights into factors which may influence data collection and the quality of data collected in order to inform best practices for citizen science schemes. In addition to this, an online survey was also carried out which asked questions regarding previous survey and citizen science experience and asked participants to gather abundance data from photographs. The different methods (actual count, percentage cover and ACFOR scale) of estimating abundance were compared again to inform best practice guidelines for citizen science schemes. This study it is hypothesised that, (1) Members of the public are generally aware of citizen science and wish to engage with it, (2) Self-scored confidence will improve after trialling citizen science methods, (3) Actual counts of species present is the most useful measure of abundance given by citizen scientists.

Methodology

The Dale Fort Citizen Science group was set up for the purpose of the study in January 2018. Citizen science sessions were held once a month for four months, to trial different citizen science methodologies. Different sets of volunteers attended each session.

Each session took a similar format:
- introduction to citizen science and the research project;
- introduction to that month’s survey, its importance and how it worked;
- completion of consent forms, gathering of emergency contacts details;
- the survey work;
- a debrief, with completion of evaluation forms.

For each participant of the survey group, age, education level, and previous survey experience was recorded. Participants were also asked to score their confidence in the survey method before and after carrying out the protocol. Confidence was scored 1 – 10 where 10 was the most confident and 1 the least. The survey days carried out were as follows:

1. Natural History Museum, Big Seaweed Search (NHM, 2018)
The first survey was the Natural History Museums, Big Seaweed Search, which aimed to survey seaweed biodiversity. On Castle Beach, Dale, three, 30m transects were set out, marked with ropes moving from the low shore line to the strandline of the beach. These were labelled consecutively. Each of the participants were given the Natural History Museum Seaweed ID Key which detailed 14 species to look out for. These were listed on the recording sheet, and the participants were required to mark either present of absent for each seaweed on each of the three transects.

2. Earth Worm Watch (Earthwatch Institute, 2018)
In this survey the method required participants to dig a 20cm x 20cm square in the soil of 10cm deep. This was carried out in the grounds of Dale Fort, in a flower bed and on a grass area for the two sites required The soil was removed, and any earthworms found were collected. A bottle of mustard water was then added to the soil pit, and any worms which appeared within five minutes were collected and stored separately to the first group. Using the Earthwatch identification chart the worms were classified as either deep living, surface feeding or soil feeding, and adult or immature. Other descriptive characters about the soil were then collected, such as its colour, and texture. This was repeated for two areas, with differing vegetation.

3. OPAL Tree Health Survey (OPAL, 2018)
All participants were issued with a protocol booklet, identification guide and survey sheet. Fifteen trees in Castle Beach woods, Dale, were marked with a number card, prior to the survey, so that data was collected about the same trees by the participants. For each tree participants were asked to identify its species, note any signs of disease, estimate height, canopy cover, and leaf density. Participants were also asked to record any signs of diseases (as shown in their ID guides) on other trees in the woodland.

4. OPAL Poll:nation Survey (OPAL 2018)
This methodology required participants to survey a 10m x 10m site, draw out the vegetation of the site on a grid, and then record how many squares were covered by each listed habitat type. They were then asked to use a species key, and record if several plants were present or in flower. Three 1m2 quadrats were then placed within the survey area, and participants were required to record several descriptive characters, for example “floweriness”. They were then asked to watch the quadrat for 1 minute and record the species of any pollinator sightings.

Online study
A questionnaire consisting of 7 questions was shared via social media to test participants ability to quantify amounts during fieldwork and to survey general experience and opinions regarding citizen science.

Statistical analysis
Statistical analysis was performed in R 3.5.1 (R Development Core Team, 2017) and IBM SPSS Statistics 24 (IBM Corp, 2016).
Normality of the data was tested using the Shapiro-Wilk in R. When data was non-parametric a Mann Whitney U test was used. The effect of the three factors (age, education and experience) on mean confidence before and after the survey were investigated using ANOVA and Kruskal Wallis (when data was non-parametric). Post

hoc analysis of significant results was carried out using the Tukey HSD test. The effect of the confidence score given by participants after carrying out the survey on the data collected on the total number of species counted in the seaweed survey and the number of trees identified correctly was investigated using Pearson's' product-moment correlation.

Results

A number of themes were investigated in this study, the first of these being participation and engagement in citizen science. Across the four survey days of the citizen science group there were a total of total of 30 participants. Two more survey days were planned but had to be cancelled due to a lack of uptake and extreme weather conditions – one being heavy rain and one a very sunny day. Attendance numbers are shown in Table 1.

Table 1: Attendance at the four survey days

Survey day	Number attended
January – Seaweed	15
February - Earthworm	4
March - Trees	9
April - Pollinators	4

The online study received a total of 80 responses. In one of the online survey questions participants were asked of their previous involvement in citizen science (Figure 1). One participant chose not to answer, but 63% of participants had shown some previous engagement with citizen science.

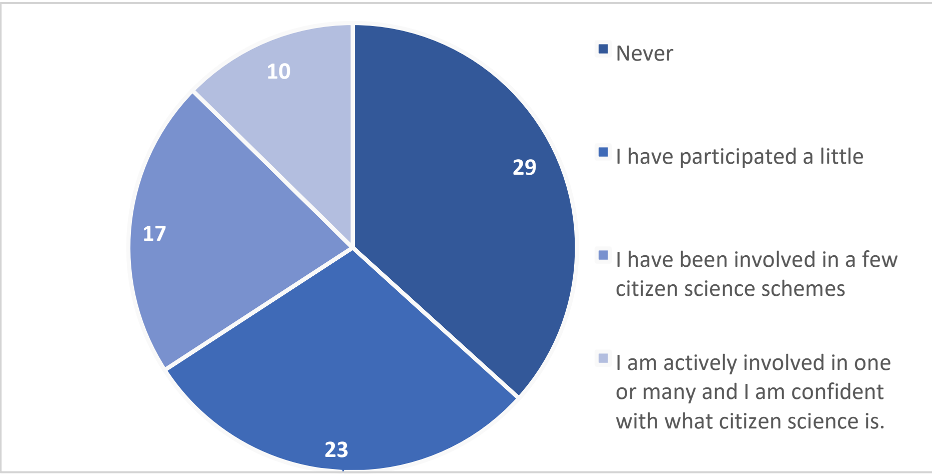

Figure 1: Responses to the question "Have you participated in citizen science before?"

Participants of the online study were also asked how important they felt it was for members of the public to be involved in biological recording (Figure 2). Here, 70% of participants acknowledged citizen science data collection was both important and could have huge potential. One participant did not answer.

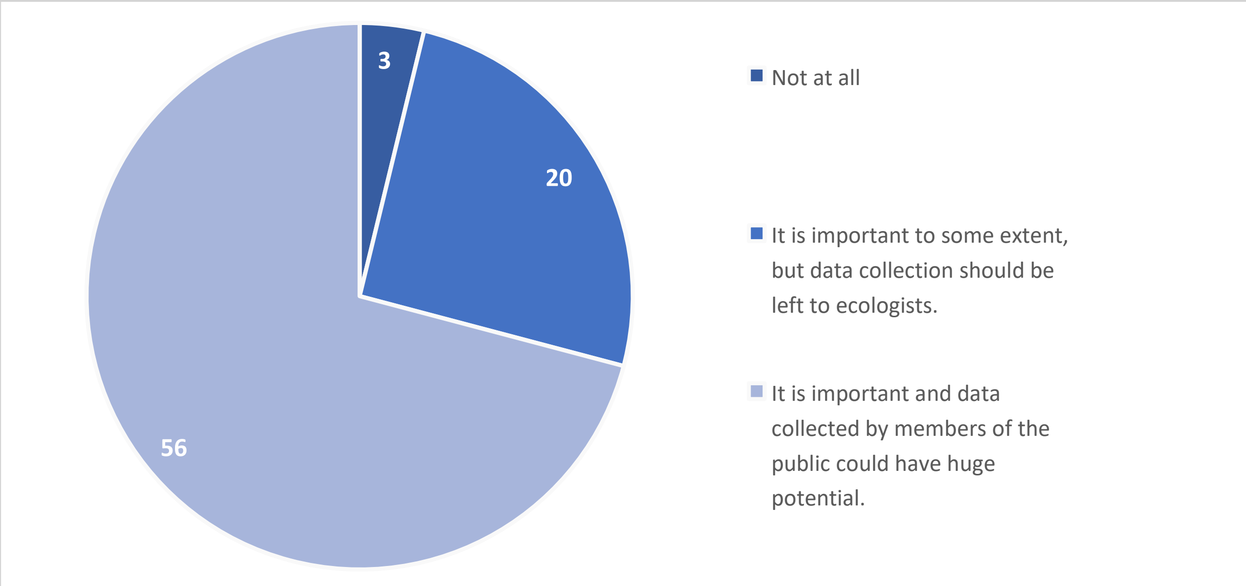

Figure 2: Responses to the question "how important do you feel it is for members of the public to engage in biological recording?"

The second theme to be addressed was confidence, which was studied in the Dale Fort Survey Group. From the 30 participants of the survey days, a mean confidence of 3.5/10 was recorded before the survey, which was shown by a Mann-Whitney test to have increased significantly (p=1.202x10-5) to 6.4 following the survey. The before and after confidence data was non-parametric (p=0.001 and 0.03). An increase in confidence was seen in all but one of the participants.

No significant difference was found in the mean confidence before or after the survey according to age (p=0.0427; p=0.0756), or education (p=0.960; p=0.122), by ANOVA test. Before the survey, no significant difference was found according to experience (p=0.2485). However, following the survey, a significant difference was seen in confidence with experience (p=0.00491). The experience data was non-parametric therefore Kruskal Wallis was used. Post-hoc analysis, by the Tukey HSD test, revealed there to be significant differences between those with limited and no survey experience (p=0.0290), those with some and limited experience (p=0.0294) and those with professional and limited experience (p=0.015).

When assessing the effect of confidence on the data collected no correlation was found between confidence and the total number of seaweed species recorded (p=0.0807; Figure 3). No correlation was found between confidence and the number of trees identified correctly (p=0.214; Figure 4). This was assessed using Pearson's' product-moment correlation as the total number of seaweed species recorded and the number of trees identified correctly were both parametric however confidence was non-parametric.

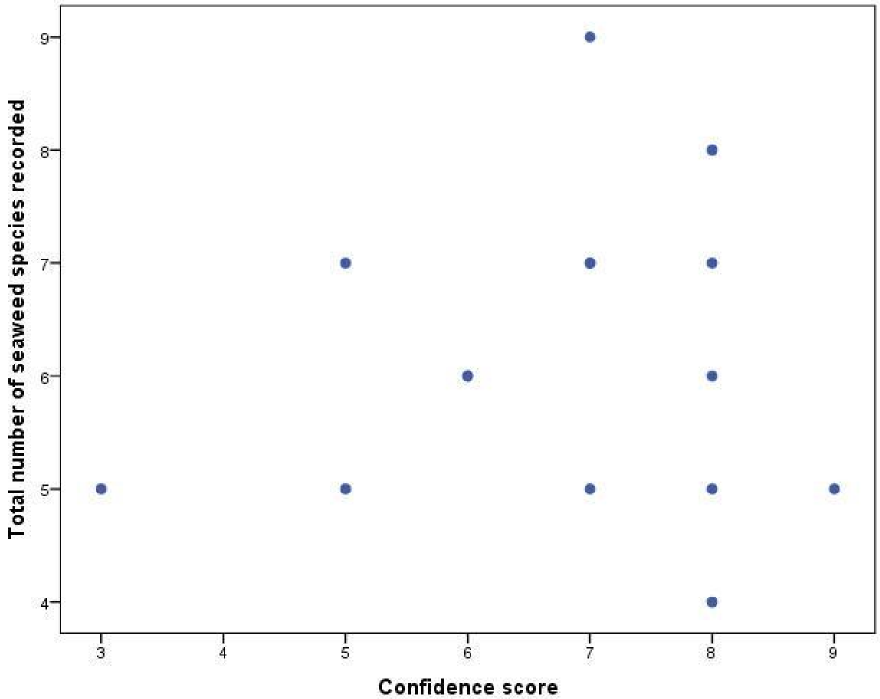

Figure 3: Total number of seaweed species recorded by participants of the Dale Fort Survey group in January 2018, plot against their confidence level. No significant correlation was found using Pearsons (p=0.0807).

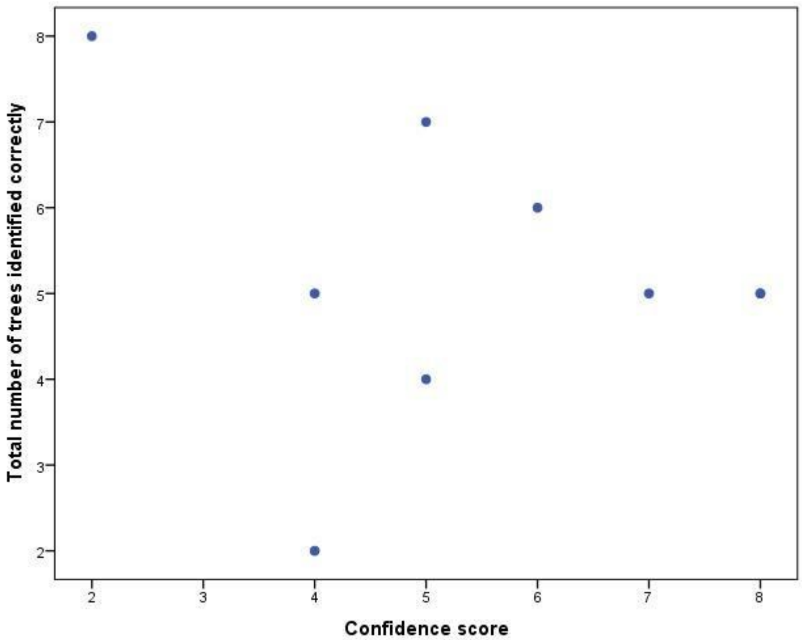

Figure 4: Number (out of 10) of trees identified correctly plot against the participants confidence level. No significant correlation was found using Pearsons (p=0.214).

The final part of this study was to compare different measures of abundance. Three difference measures of abundance were trialled in the online study. The first of these being an actual count of the number of species present in a photograph of a quadrat (Figure 5). The mean number was 6 species.

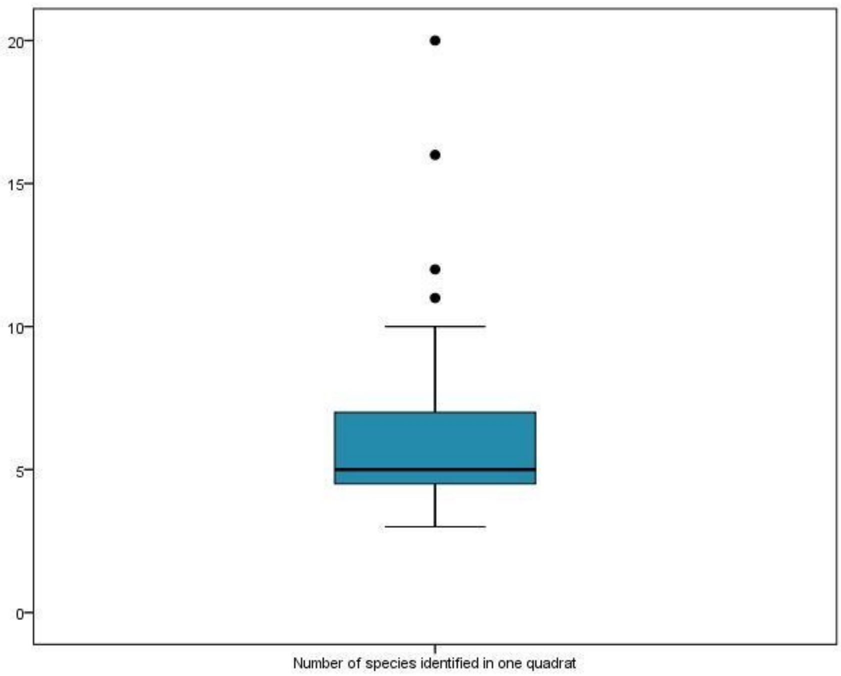

Figure 5: The number of species present in a photographed quadrat, identified by participants.

Participants were also asked to estimate the percentage cover for 3 of the species present in the quadrat (Figure 6). Three participants answered over 100% for one of the species.

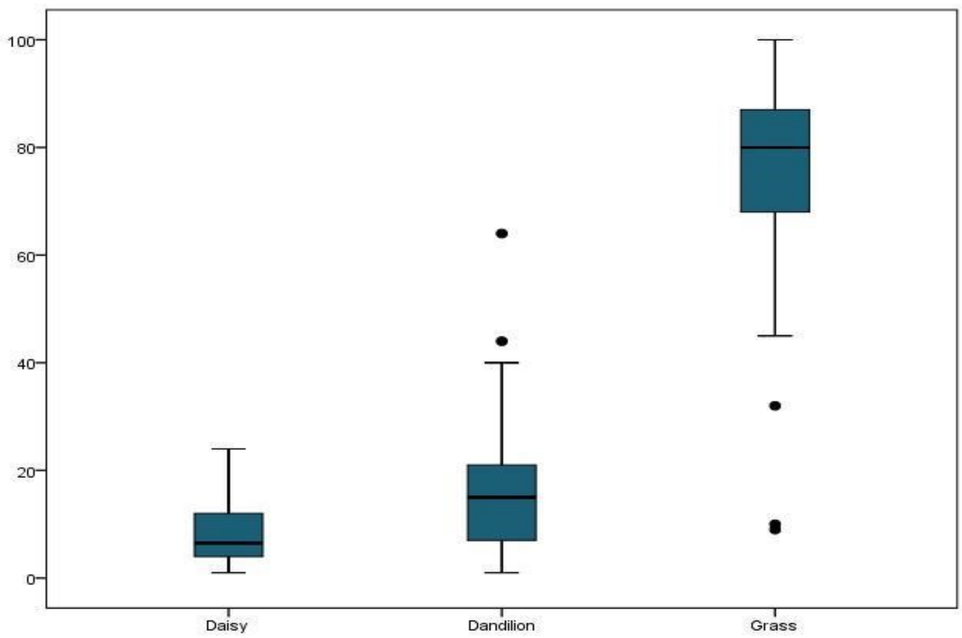

Figure 6: Participant answers when asked to estimate percentage cover of three species in a photograph of a quadrat. Answers over 100% have been removed.

The final method was quantification of abundance using the ACFOR scale. Only 66 participants answered this question. Participants were asked to quantify abundance for three groups present in the quadrat – grass, yellow lichen and bare rock. Between the 66 responses an answer was given in every point of the ACFOR scale for each group (Figure 7).

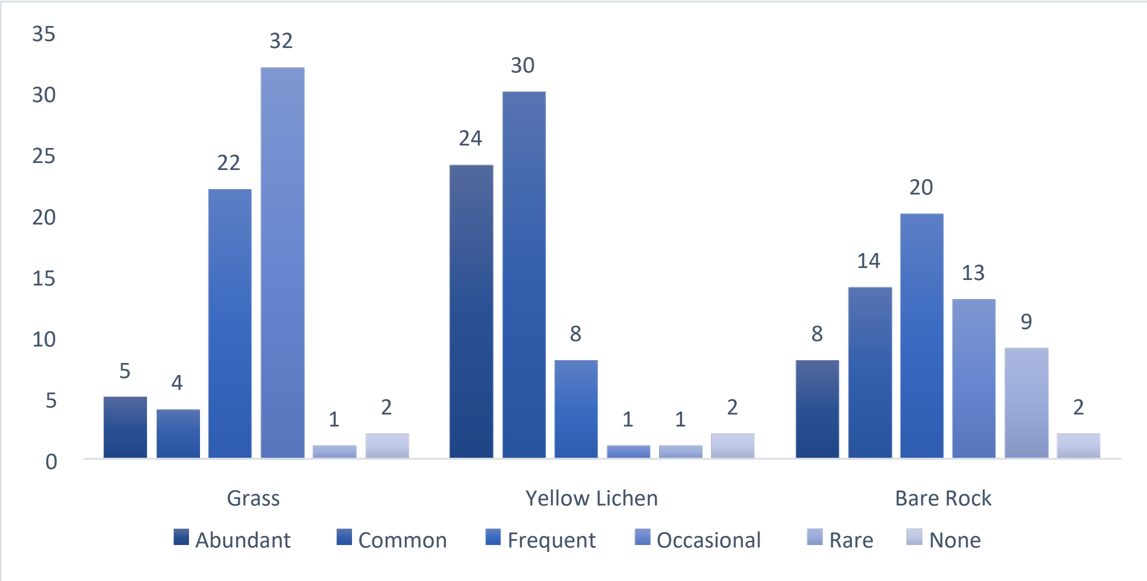

Figure 7: Categorisation using ACFOR for three groups identified in a photograph on a quadrat.

Discussion

Citizen science already attracts many volunteers; 63% of those who answered the online survey had previously engaged with citizen science on some level. Furthermore, 70% of participants felt citizen science was important, and had the potential to be a significant provider of ecological information. This is supported by Bonney et al. (2014) who describes that globally “thousands” of citizen science projects are reaching “millions” of people. One of the UK’s major citizen science providers is OPAL, who in their 2016 report claimed to have reached 965,000 beneficiaries since their launch (OPAL, 2016). It is, therefore, undeniable that citizen science has a considerable audience.

West and Pateman, (2016) deduce that it is important in the creation of citizen science projects to outline clearly the expectations of the project, in order to appeal to a range of motivations. It can also be useful to gather information of the demographic attending in order to allow organisers of citizen science projects to focus their project on a wide range of people. This was true in the case of the Dale Fort survey group – different participants attended the different surveys. Verbal feedback from the participants suggested that at the seaweed survey day were people who wished to know more about the seaweeds on the beach, whereas those attending the earthworm day were interested in gardening and improving soil health. Different topics motivated different people to attend, therefore it can be useful to gather information from participants about their reasons for attending to inform future advertising and in turn increase participation.

Most of the projects described in this study can be considered contributory; in which the public collect data in order to answer questions pre-designed by scientists (Bonney et al., 2009). In these projects' citizen scientists are involved mainly in data collection, and therefore it is important that data is collected accurately and that protocols are repeatable through the wider public. In order to asses understanding "confidence" was used as a measure. Participants of the Dale Fort survey group were asked to give a confidence score for how they felt prior to completing the protocol and after the survey. Confidence was shown to increase following practical experience of the survey, suggesting the important of training and trial days for citizen science schemes.

Given that carrying out a new method in a survey group showed significant increases in confidence, training of citizen scientists is likely to also improve confidence. Training may also lead to greater accuracy in data collection. However, whilst in-person training is effective, this process can be both expensive and time consuming (Starr et al., 2014) which contradicts the ethos of citizen science (as a provider of large data sets and low cost).

Analysis of the confidence data showed no relationship between confidence and ability. In the case of the seaweed search, there was no relationship between the number of species marked present or in the case of tree health the number of trees identified correctly. Therefore, it is important to note that just because a participant is confident in a method, it does not mean their data will be accurate, and so other methods should be used in order to assess the quality of their data. Inaccuracy in data collections is the main criticism of citizen science. Gardiner et al., (2014) did identify a threshold at which, when enough data was collected, the influence of recorder error would not affect the interpretation of the data (Gardiner et al., 2014). Crall et al., (2011) also showed that misidentification can be a major problem in citizen science data collection, however they suggest that this can be overcome with the verification process.

Data verification can increase the cost and time investment in citizen science schemes. However, a review by Wiggins et al., (2011) suggested that although it appears the method of data validation is related to human and fiscal resources there is no strong correlation to support such notion. In general, validation method is chosen based upon the nature of the data. One such method discussed is data mining. This is a validation process which measures the value of date from one source in comparison to another benchmark source (Munson et al., 2010). Data validation was not considered in this study; however, it is a novel method to increase the usability of citizen science data in terms of scientific research.

The online survey compared three methods of quantifying abundance – actual counts, percentage cover and the ACFOR scale. The first question showed a photograph of a quadrat, and asked participants how many different species they could see. This would give an indication of species richness. Richness is a useful measure to describe both community and regional diversity (Gotelli and Colwell, 2001). This question did not require participants to identify the species or to estimate their abundance, simply to count how many different species there were. Answers ranged from 3 to 20, from the 79 survey participants.

However, simply knowing how many different species are present isn't all that useful. Ideally, ecologists need to obtain detailed records – but identification can be a big challenge in citizen science. This was shown in the tree survey carried out by the survey group – where correct identification averaged at 56% of the time. However, identification errors can be addressed with data validation. For example, Project Feeder Watch introduced 'smart filters' at the data input stage (Bonter and Cooper, 2012). This produced an allowable list of species and flags when participants entered species which had been recorded by less than 4% of participants in the area. This would give a warning message which would result in either participants correcting their record or an 'invalid record' being created which would be investigated by professionals. This method proved useful in removing implausible records, however it did not question incorrect records which would be plausible for that date and location. It was suggested that this problem could be overcome with online quizzes and games designed to identify which species are likely to be mis-recorded. Another suggestion is to track participants who frequently submit questionable observations (Bonter and Cooper, 2012).

Alongside identification, measures of abundance can also be useful for citizen scientists to obtain. In this study the use of percentage cover and the ACFOR scale was trialled. Participants were asked to estimate the percentage cover for three species in a photograph of a quadrat. On three occasions answers of over 100% were given, and 79 participants attempted the question. Range was much higher for percentage cover however the mean estimates were in line with the 'correct' values. Visual estimation is a highly subjective measure but has been shown to be a legitimate technique for estimating percentage cover (Deither et al., 1993). The method is relatively simple however relies on precision in estimation – in this case more variation in the answer was seen at a high percentage cover. The measure may be useful, however would again require validation.

The ACFOR scale requires participants to assign a category – "abundant", "common", "frequent", "occasional" or "rare" to estimate abundance of certain species. In the survey participants were given a photograph of a different quadrat and asked to assign a category from the scale to three species. Participation for this question was much lower (only 66 participants attempted it). This would suggest that 17.5% of participants struggled with the question. In addition to this for the three species, participants answered in every single category, suggesting this method of quantifying abundance is much less useful than percentage cover. The ACFOR scale is also a qualitative measure of abundance, which may be less useful than percentage cover. The methods used to quantify abundance need to be specific to the projects aim.

With these findings in mind it appears 5 key principles can be suggested as guidelines for using citizen science in biological investigations:

1. Projects should be designed considering participant motivations and in a way that allows for clear explanation of the expectations of participants.
2. Training of citizen scientists is important (both to improve their own confidence and the quality of the data). Online training provides a viable, cost-effective option.
3. Methods of data collection need to be designed specific to the project however should be kept as simple as possible, in order to minimise error.

4. Potential errors in data collection should be identified and targeted through training programmes.
5. Validation is an important step in using data collected by members of the public. Validation should be built into the data collection and training.

Conclusions

Considering the hypothesis, it is concluded that (1) citizen science has reached a good level of popularity amongst the general public and people do wish to engage in biological recording; (2) participant confidence does increase after carrying out a given method; (3) the most appropriate method of quantifying abundance is dependent upon specific project aims. It is also concluded that we should invest time and resources into validation scheme and online training of participants. Further research is required into developing the most appropriate training and validation methods. We need to investigate the most appropriate ways to identify “quality” data collection and how this can be embedded into the training process.

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